ANSI_NEMA_ANSLG C78.377-2008

American National Standard

for electric lamps—

Specifications for the Chromaticity of Solid State Lighting Products

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American National Standard

Approved: January 9, 2008 Secretariat: American National Standard Lighting Group

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Specifications for the Chromaticity of Solid State Lighting Products

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Foreword (This foreword is not part of American National Standard C78.377-2008.)

This is a new standard recently developed by the industry.

Suggestions for improvement of this standard should be submitted to the Secretariat C78, American National Standard Lighting Group, 1300 North 17th Street, Suite 1752, Rosslyn, VA 22209.

This standard was processed and approved by the Accredited Standards Committee on Electric Lamps, C78, and the National Electrical Manufacturers Association Solid State Lighting Section technical work group (known at the time as 78 Work Group 09). Committee approval of the standard does not necessarily imply that all committee members voted for that approval.

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Revision	C78_4270	C78_4271

Dennis Holt, Chair, ASC78
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Organization of this standard

This standard has been arranged in two parts.

One part includes information on the chromaticity specification basis, explanation of a nominal CCT and target CCT, details of SSL chromaticity requirements, and definition and specification of color rendering index. This part includes tabled information relative to these portions of the standard.

The other part is comprised of a large informative annex, which provides some background information and the technical context in which this chromaticity specification for the SSL products was developed.

The annex includes tabled information on the chromaticity coordinates of the center points and the four corners of each quadrangle for convenience of plotting these quadrangles.

The annex also includes three graphical representations split into two figures (A1 and A2) of the chromaticity specification of SSL products in the tabled information on the CIE (*x,y*) chromaticity diagram and the (*u',v'*) chromaticity diagram (Figure A1), and an example of chromaticity tolerance of Flexible CCT at nominal CCT of 3200K (Figure A2).

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1. Scope

The purpose of this standard is to specify the range of chromaticities recommended for general lighting with solid state lighting (SSL) products, as well as to ensure that the white light chromaticities of the products can be communicated to consumers. This standard applies to LED-based SSL products with control electronics and heat sinks incorporated, that is, those devices that require only AC mains power or a DC voltage power supply to operate. This document does not cover products that require external operating circuits or additional external heat sinks. This document covers fixtures incorporating light sources as well as integrated LED lamps[1]. This document does not cover fixtures sold without a light source. The chromaticity requirement in this standard is for general indoor lighting applications. For other applications, chromaticities of light broader than the range specified in this standard are often acceptable. This standard does not cover SSL products for outdoor applications. This standard also does not cover SSL products for some indoor applications that intentionally produce tinted or colored light.

1.1 Important Patent Disclaimer

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2 Normative references

***ANSI C78.376-2001**, Specifications for the chromaticity of fluorescent lamps.*

***CIE 13.3-1995**, Commission Internationale de l'Eclairage, Method of Measuring and Specifying Colour Rendering of Light Sources.*

***CIE 15: 2004**, Commission Internationale de l'Eclairage, Colorimetry, 3rd edition.*

IESNA LM-79-07[2], Illuminating Engineering Society of North America, Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products.

***Specification of Small Chromaticity Differences**, D. L. MacAdam, Journal of Optical Society of America, 33-1, 1943, pp 18-26. (referred to hereafter as "*MacAdam ellipses").

U.S. Department of Energy (DOE) Energy Star Program Requirements for CFLs Partner Commitments** – version 4.0, 2007.**

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[1] Integrated LED lamps are light sources with a standardized base that are meant to connect to the branch circuit via a standardized lampholder/socket, (e.g., replacement of incandescent lamps with screw base).

[2] To be published

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3. Chromaticity specification basis

The chromaticity coordinates and correlated color temperature (CCT) values used in this specification are based on the CIE[3] colorimetry system. The specifications in this standard are in part based on ANSI C78.376 on chromaticity specifications for fluorescent lamps but modified to meet the needs of SSL products. The fluorescent lamp chromaticity tolerances are based on MacAdam ellipses that define perceptible color differences.

While the chromaticity of light is expressed by chromaticity coordinates such as (*x, y*) and (*u', v'*), the chromaticity of white light can also be expressed by CCT and the distance from the Planckian locus. CCT is a more intuitive measure of the shade of white light than (*x, y*). Since CCT is defined based on the (*u'*, 2/3 *v'*) chromaticity diagram[4], the distance from the Planckian locus should be determined on the same diagram. It should be expressed as a signed value to indicate whether the chromaticity is above or below the Planckian locus. As such a distance parameter with respect to the Planckian locus is not officially defined by the CIE, "Duv" is defined in this document as the closest distance from the Planckian locus on the (*u'*, 2/3 *v'*) diagram, with + sign for above and - sign for below the Planckian locus.

4. Nominal CCT and Target CCT

Nominal CCT is used to specify and communicate white light chromaticity information of a product, and, in this document, is a CCT value at 100 K steps that is closest to the target CCT of the product. A target CCT is the CCT value that the product is designed to produce. Individual samples of the product may deviate from the target CCT due to production variation, which is normally controlled to be within a production tolerance. The same applies to target Duv. The target CCT and target Duv are also the center points of the tolerance range of these parameters in this document.

5. Chromaticity requirements

SSL products covered in this standard shall have chromaticity values that fall into one of the nominal CCT categories listed in Table 1. SSL products with a given nominal CCT shall have the defined target CCT and Duv, and the values of individual samples shall be within the tolerances of CCT and Duv as listed in Table 1. Measurement of chromaticity shall be made in accordance with methods given in the measurement standard IESNA LM-79.

[3] International Commission on Illumination
[4] equivalent to the CIE 1960 (*u, v*) diagram, now obsolete.

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Table 1 - Nominal CCT Categories

Nominal CCT[1)]	Target CCT and tolerance (K)			Target Duv and tolerance		
2700 K	2725	±	145	0.000	±	0.006
3000 K	3045	±	175	0.000	±	0.006
3500 K	3465	±	245	0.000	±	0.006
4000 K	3985	±	275	0.001	±	0.006
4500 K	4503	±	243	0.001	±	0.006
5000 K	5028	±	283	0.002	±	0.006
5700 K	5665	±	355	0.002	±	0.006
6500 K	6530	±	510	0.003	±	0.006
Flexible CCT (2700 - 6500 K)	T [2)]	±	ΔT [3)]	D_{uv} [4)]	±	0.006

1) Six of the nominal CCTs correspond to those in the fluorescent lamp specification [2]: 2700 K, 3000 K (Warm White), 3500 K (White), 4100 K (Cool White), 5000 K, and 6500 K (Daylight), respectively.
2) T is chosen to be at 100 K steps (2800, 2900, …., 6400 K), excluding those eight nominal CCTs listed in Table 1.
3) ΔT is given by $\Delta T = 0.0000108 \times T^2 + 0.0262 \times T + 8$.
4) D_{uv} is given by $D_{uv} = 57700 \times (1/T)^2 - 44.6 \times (1/T) + 0.0085$.

Note 1: The chromaticity tolerances specified above are given as quadrangles rather than ellipses on the chromaticity diagrams. The sizes of the quadrangles correspond approximately to those of 7-step MacAdam ellipses used in the compact fluorescent lamp chromaticity specification. See Annex A for a graphical representation of the specifications in Table 1.

Note 2: The range of Flexible CCT values overlaps with the ranges of the other eight defined CCTs. Flexible CCT is used to specify products that have nominal CCTs other than the defined eight nominal CCTs in Table 1.

Note 3: The values of nominal CCT are used to specify and communicate chromaticity information of the product.

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6. Color Rendering Index (R_a)

6.1 Definition

Color rendering index (CRI) is a measure of how similar object colors appear under illumination by a test source compared to the object colors under a reference illuminant (Planckian radiation or a phase of daylight) of the same CCT. For the purposes of this standard, reference to CRI as a characteristic of SSL products is taken to mean the "General CRI" identified as R_a in CIE 13.3. R_a is calculated from the relative spectral power distribution of the source.

6.2 Specification

The average of the R_a of SSL product samples shall be equal to or higher than the specified minimum R_a, with all individual samples equal to or greater than the average R_a value minus 3. Measurement of the spectral power distribution of the product sample shall be in accordance with IESNA LM-79. The calculation of R_a shall be in accordance with CIE 13.3.

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ANNEX
(Informative)

A.1 Introduction

This annex provides some background information and the technical context in which this chromaticity specification for SSL products was developed.

The purposes of this standard are, first, to specify the range of chromaticities recommended for general lighting with solid state lighting products to ensure high quality white light and, second, to categorize chromaticities with given tolerances so that the white light chromaticity of the products can be communicated to consumers. For this second purpose, the existing chromaticity standard (ANSI C78.376) for fluorescent lamps (FLRs) uses six nominal CCTs, some of which are given names such as Warm White (3000 K), Cool White (4100 K), and Daylight (6500 K). These names are often printed on product packages to communicate nominal CCT of the products to consumers. 2700 K and 5000 K, however, do not have names. Each of the six FLR lamp nominal CCTs has tolerances given as ellipses in the (*x, y*) chromaticity diagram. Four-step MacAdam ellipses are used in ANSI C78.376 and seven-step MacAdam ellipses are used in the Department of Energy (DOE) Energy Star program (version 4.0) for Compact Fluorescent Lamps.

This chromaticity specification for SSL products was developed, on one hand, to be as consistent as possible with the existing fluorescent lamp standards, since major applications, at least in the initial stages of commercialization, are considered to be for replacement of existing fluorescent lamps and luminaires as well as those of incandescent lamps. On the other hand, there are several different requirements to be considered to best reflect the current (and near future) state of the SSL technologies. Since the SSL technologies are still at their early stages, control and stability of chromaticity of light are not as well established as with fluorescent lamps. These aspects were considered to some extent when determining the tolerances of chromaticity in this standard, while acknowledging that smaller tolerances would be preferred. Therefore, this standard is of interim nature, and the contents of this standard will need to be updated as SSL technologies advance and more applications are developed.

Figure A1 shows the graphical representation of the specification of the SSL products as listed in Table 1 on the (*x, y*) and (*u', v'*) diagrams. The (*u',v'*) diagram is more uniform than the (*x, y*) diagram and is better suited for evaluating color differences of light sources. Table A1 below shows the (*x, y*) chromaticity coordinates of the center points and the four corners of each quadrangle for convenience of plotting these quadrangles. Note that the sides of the quadrangles along the Planckian locus are not exactly straight lines but slightly curved so that the Duv value is constant.

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Table A1 – Specification of the SSL Products in Table 1

	2700 K		3000 K		3500 K		4000 K		4500 K		5000 K		5700 K		6500 K	
	x	y	x	y	x	y	x	y	x	y	x	y	x	y	x	y
Center point	0.4578	0.4101	0.4338	0.4030	0.4073	0.3917	0.3818	0.3797	0.3611	0.3658	0.3447	0.3553	0.3287	0.3417	0.3123	0.3282
Tolerance Quadrangle	0.4813	0.4319	0.4562	0.4260	0.4299	0.4165	0.4006	0.4044	0.3736	0.3874	0.3551	0.3760	0.3376	0.3616	0.3205	0.3481
	0.4562	0.4260	0.4299	0.4165	0.3996	0.4015	0.3736	0.3874	0.3548	0.3736	0.3376	0.3616	0.3207	0.3462	0.3028	0.3304
	0.4373	0.3893	0.4147	0.3814	0.3889	0.3690	0.3670	0.3578	0.3512	0.3465	0.3366	0.3369	0.3222	0.3243	0.3068	0.3113
	0.4593	0.3944	0.4373	0.3893	0.4147	0.3814	0.3898	0.3716	0.3670	0.3578	0.3515	0.3487	0.3366	0.3369	0.3221	0.3261

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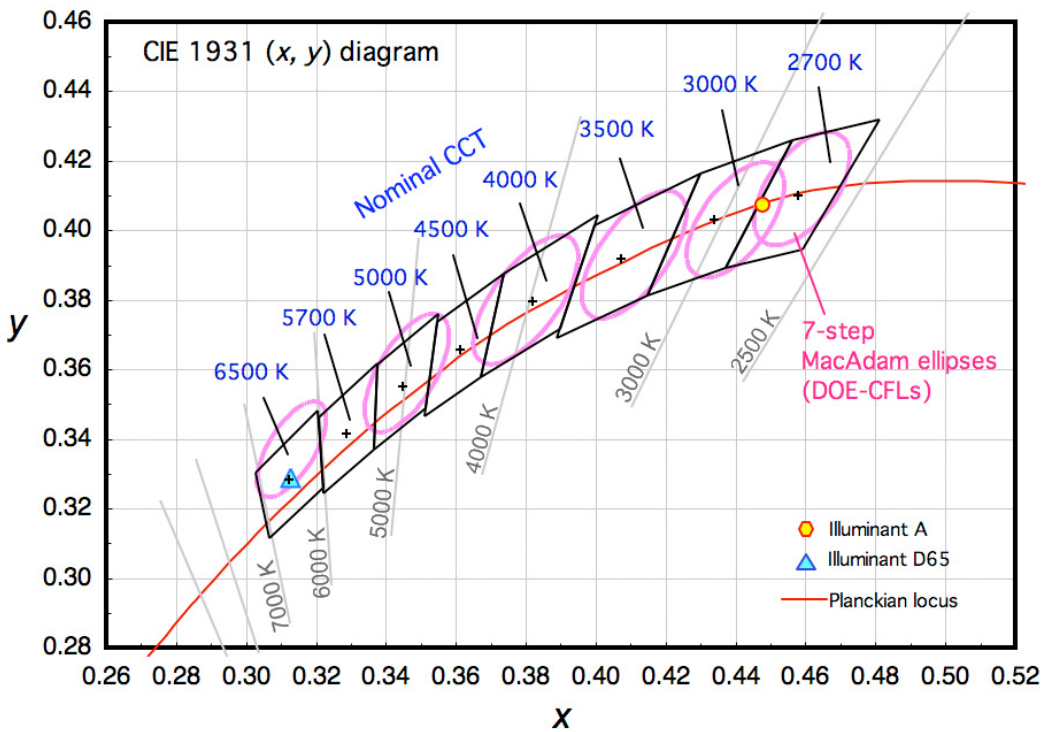

Figure A1, Part 1
Graphical representation of the chromaticity specification of SSL products in Table 1, on the CIE (*x*,*y*) chromaticity diagram

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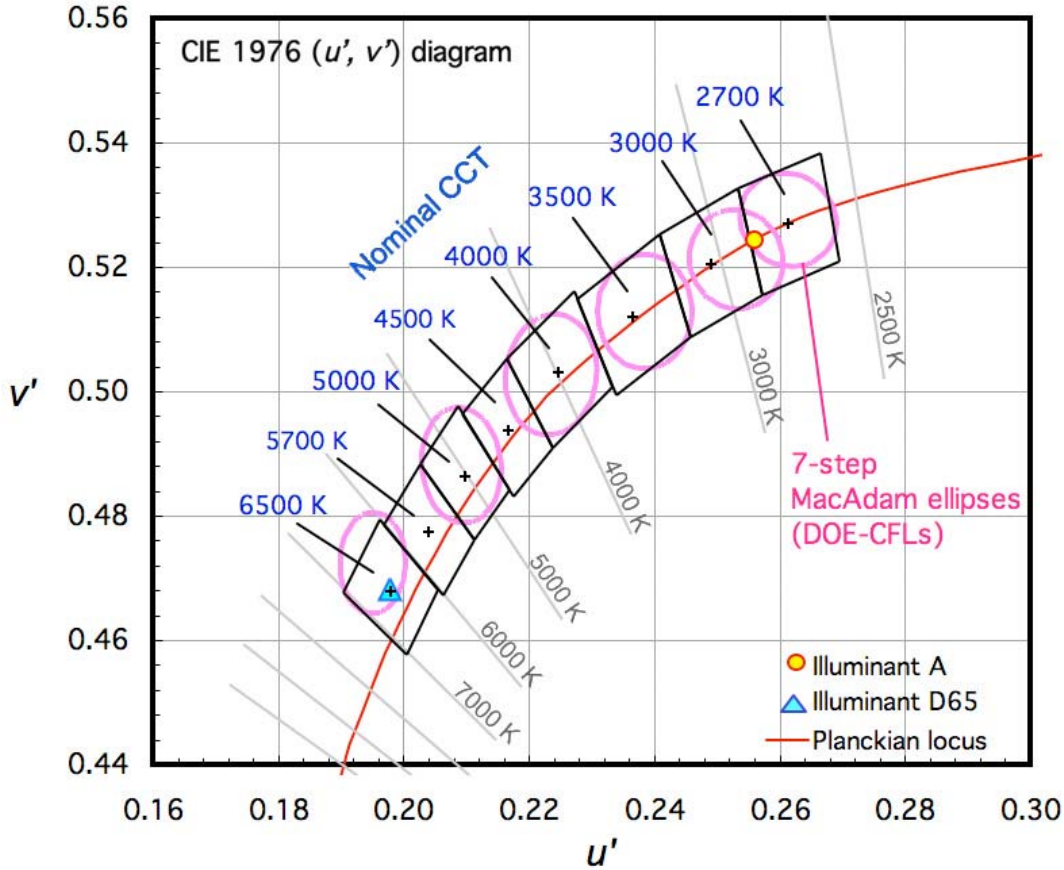

Figure A1, Part 2
Graphical representation of the chromaticity specification of SSL products in Table 1, on the CIE (*u'*,*v'*) chromaticity diagram

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This standard includes two systems of chromaticity specification, one based on the ANSI C78.376 fluorescent lamp (FLR) standard with fixed target CCTs (the first eight nominal CCTs in Table 1), and another based on flexible CCT (Flexible CCT in Table 1). Either of the two systems may be used.

A.2 FL chromaticity-based system

This system may be used for applications targeting replacement of existing fluorescent lamps or luminaries by SSL products, thus keeping consistency with FLR chromaticity specifications as much as possible. This same system (2700K, 3000 K) may be used for the replacement of incandescent and halogen systems. Eight nominal CCTs are specified, six of which are consistent with the ANSI C78.376 FLR specification. The chromaticity tolerance ranges are given by quadrangles that are mostly overlapping with the 7-step MacAdam ellipses defined in the CFL Energy Star specification (version 4.0) for the six nominal CCTs.

Quadrangles rather than ellipses are used for SSL products for the following reasons: 1) quadrangles are commonly used in chromaticity binning of LED products, 2) due to cost-effective binning of LEDs and products, the gaps between chromaticity ranges need to be as small as possible, and 3) quadrangles can be specified by the CCT and Duv, and it is easier to judge product acceptance using the quadrangles than using ellipses. Eight quadrangles are defined to cover the CCT range from 2700 K to 6500 K.

From the current state of SSL technologies, it was considered that continuous coverage of the broad CCT range was extremely important for cost-effective yield of white LEDs produced. If there are gaps between quadrangles, many products or sources would need to be rejected. To address this concern, two additional nominal CCTs (4500 K and 5700 K) have been added to fill the gaps between the quadrangles of 4000 K and 5000 K and between 5000 K and 6500 K of the original FLR nominal CCTs. Furthermore, the size and positions of all the quadrangles are adjusted so that there are no gaps and no overlaps in between them. With these adjustments, the entire CCT range from 2700 K to 6500 K is covered continuously with the eight quadrangles with no gaps, while still maintaining reasonable consistency with the six FLR chromaticities. To achieve this and to maintain approximately equal tolerance ranges, the target chromaticities were moved slightly from the FLR target chromaticities.

Some nominal CCT names (Warm White, White, Cool White, and Daylight) have been used in the ANSI C78.376 FLR specification for many years, and these names have been used as a means of communication with general consumers. However, nominal CCTs of 2700 K and 5000 K did not have names. Two new nominal CCTs have been added in this standard, so there are four CCTs that do not have names. The committee considered that adding four new names, making eight names in total, would not successfully work as an effective means of communication. The committee decided not to use such names, and instead, recommends using the value of nominal CCT or some as yet unspecified alternate means to communicate the nominal CCT to general consumers.

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There was a view that specifying only the ranges of tolerance without target point CCT and Duv would be sufficient. Target CCT and Duv, however, are given in this document with an expectation that products are designed to produce these center points so that individual variation of chromaticity will center around the target point, and thus, the average chromaticity of products among different manufacturers should match closely. Also, if the tolerance ranges are reduced in the future, the same target CCT and Duv should be used so that continuity of chromaticity is maintained.

A.3 Flexible CCT system

Under the FLR chromaticity-based system described above, nominal CCTs are limited to the eight values given in Table 1. There were concerns that this limitation may inappropriately restrict the flexibility of SSL technology. For example, some products may have variable CCT, meeting the chromaticity requirements at each controlled CCT. Another point of view was that, when SSL products are used in new installations, consistency with FLR may not be relevant. SSL products having a nominal CCT of 3200 K or 3700 K, for example, may provide a more desired shade of white light for some users, while keeping the same relative chromaticity tolerance.

Considering these points of view, the second system based on flexible CCT (Flexible CCT in Table 1) was proposed and accepted. Under this system, any CCT between 2700 K and 6500 K at 100 K steps can be used for nominal CCT. The tolerances of CCT and Duv are calculated using the defined equations and a corresponding quadrangle is given, which has approximately the same size as the 7-step MacAdam ellipses. See an example in Fig. A2. To avoid confusion and to maintain consistent tolerance ranges, Flexible CCT is only to be used to specify products that have nominal CCTs other than the defined eight nominal CCTs in Table 1.

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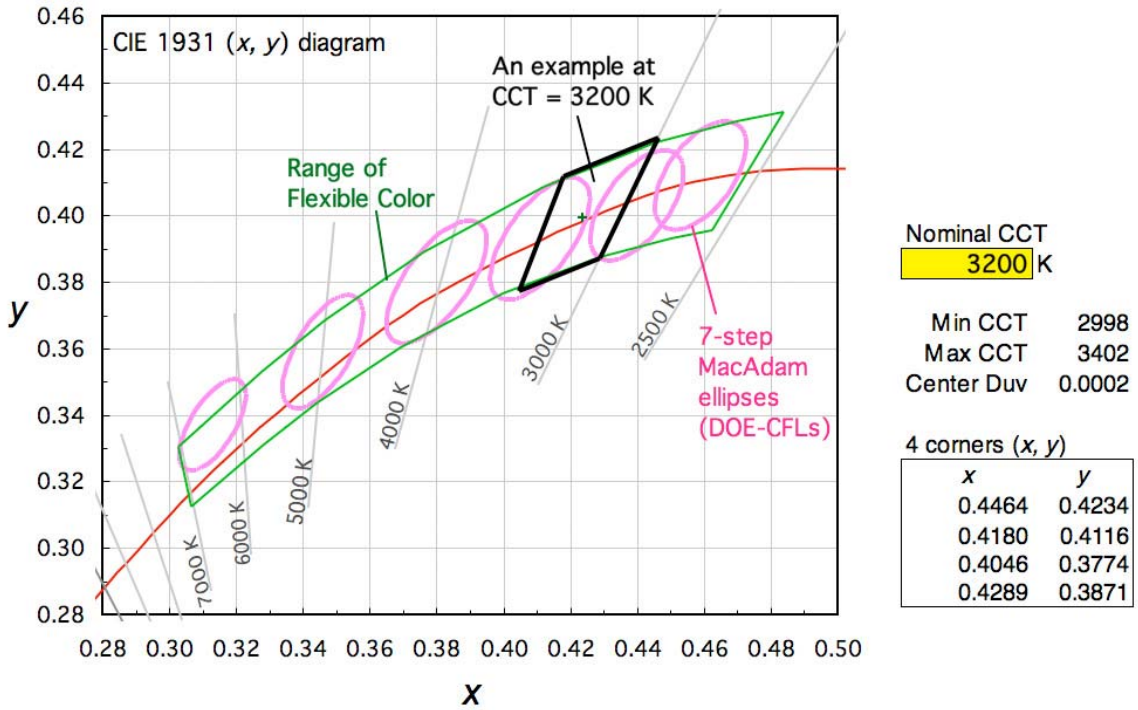

Figure A2
An example of chromaticity tolerance of Flexible CCT at nominal CCT of 3200 K.

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Note that the value of the center Duv gradually shifts from 0.000 for low CCTs to 0.003 at 6500 K (on both the FLR-based and Flexible CCT systems) based on the fact that the reference daylight (CIE standard illuminant D65) has a Duv of 0.003. This deviates from the center point of the Daylight FLR specification, which was based on available lamp products at the time the original standard was developed and does not represent Duv of real daylight. For this reason, the Duv values and target CCTs in this standard do not follow exactly those of the FLR specification but are chosen to be reasonably close to the FLR specification.

Since nominal CCT names are abandoned in this standard, chromaticity information must be communicated by nominal CCT. It is known, however, that the four-digit CCT values are not effective for communicating nominal CCTs to general consumers, and a different approach for this communication will be necessary. It is recommended that information on nominal CCT (e.g., an alternative index or figure to indicate CCT) be shown on product package for communicating nominal CCTs. To avoid confusion in the market, it is recommended that a unified method be developed for all SSL products.

A.4 Choice of chromaticity specification method

Depending on intended applications and whether compatibility of chromaticity with fluorescent lamps is considered important, manufacturers can choose one of the two specification systems to design the chromaticity of SSL products and to communicate the nominal CCT. A concern was raised as to whether the existence of two methods may cause confusion in the industry and market. However, since the SSL technologies are still in their early stages, it was decided to keep both specification systems in this standard.

Another consideration is that the chromaticity tolerance ranges (currently similar to those of the DOE - CFL Energy Star v4.0) may be reduced in the future. The ANSI C78.376 specification for FLR uses four-step MacAdam ellipses, and it is anticipated that similar level of tolerances can be adopted as SSL technologies advance in the future. When this occurs, the tolerance quadrangles will become smaller, and the quadrangles of the FLR-chromaticity-based system would no longer cover the chromaticity space continuously. In this case the Flexible CCT system would provide continuous coverage.

In section 6, Color Rendering Index (CRI) is referred to as the metric to be used. While recognizing the fact that CRI is outdated and known to have problems when used for some white LED spectra, a decision was made to use the CRI for this ANSI standard version since the CRI is still the only internationally agreed metric for color rendering of light sources. Work is in progress in the CIE to develop an improved metric. When such a new CIE standard on color rendering is published, this ANSI C78.377 standard is to be revised to update the specification for color rendering.

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